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Energy conservation in artificial lighting

The rising cost of electrical power is an incentive to consider ways of reducing the consumption of the lighting installation, certainly in large buildings and possibly in the home, if this can be done without lowering standards; in new buildings it is important to plan for the optimisation of energy use for lighting to achieve the desired visual standards.

Lighting requirements are essentially subjective; there is a large range of conditions over which the eye peforms satisfactorily, and there is equally a large range of variation among individuals as to what constitutes satisfactory conditions. Enough experience now exists, however, to indicate the way in which both performance of difficult visual tasks and satisfaction vary with quantity of light in terms of the average response of a large population and of the spread of individual responses about this mean. The effect of age on seeing is also well-known, as is the effect of brightness contrast on the resulting discomfort glare experienced by the occupants of a room.

Since energy consumed in any system is the product of power rate and time (watts and hours), reduction of either or both of these can reduce consumption. This digest first considers making the most use of the power delivered to the light sources, both in terms of conversion into light and of efficiency in providing optimum conditions for seeing the task; it then deals with measures leading to shorter periods of operation of the light sources. The digest then discusses the effects of these measures on savings in energy and the cost implications of adopting them.

Lighting uses about four per cent of the UK's primary energy and of this 92 per cent is associated with buildings. As a proportion of the electrical energy generated, however, lighting accounts for some 15 per cent, and in a large, modern air-conditioned building, about half the annual consumption is accounted for directly by the lighting, with a further contribution by the lighting to the refrigeration load. By contrast, domestic lighting and appliances account for only six per cent of the total primary energy used, most of the consumption being shared between space and water heating and cooking. Here, but more particularly in commercial and industrial buildings without mechanical cooling, lighting can to some extent reduce the heating load because all its power is eventually degraded into heat.

Standards of lighting generally recognised in the UK and widely adopted are those recommended by the IES Code*. The illuminances recommended for various seeing tasks are neither minima nor optima; the Limiting Glare Indices, which limit the possibilities of discomfort glare, are, however, maxima.

Since it is clearly meaningless to be able to state a minimum acceptable illuminance for a given task, it must be left to individuals to decide what reduction of standards they wish to accept or impose, and what reduction of satisfaction, working accuracy and productivity can be accepted as a result. But a more meaningful approach is to consider how recommended standards can be met with less consumption of energy.

*IES Code for Interior Lighting 1977 (obtainable from CIBS Lighting Division).

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Optimum use of power

The following recommendations apply equally to existing buildings and to the design of installations for new buildings. Most of them apply to dwellings as well as to non-domestic buildings, although the choice of sources is more limited for the former. If the recommendations are followed, it may be possible to reduce the electrical loading, or at least to obtain better lighting for the same loading.

Use light sources which have the highest 'efficacy' (the ratio of light output in lumens to the power in watts consumed by the circuit).

Fluorescent lamps are available in wattages and colours suitable for most commercial and domestic interiors and provide up to five times as much light for the same power consumption as ordinary incandescent lamps. Care has to be taken however over the choice of the colour and colour rendering of the lamp for the purpose required and it must be borne in mind that the stated wattage of the lamp does not include the consumption of the necessary gear for starting and controlling the discharge: this can amount to 20 per cent of the power delivered to the lamp. The introduction of solid-state electronic ballasts could, however, improve this efficiency greatly.

High pressure mercury and sodium discharge lamps are available up to thirty times more powerful than the largest fluorescent lamps, but their colour characteristics are different again from those of the familiar incandescent lamps. These two characteristics make them more suitable for industrial interiors where they can be mounted at a high level although the lower wattages, (more particularly the mercury lamp with halide additive) have been used successfully in shops and offices.

Discharge lamps last four to seven times as long as general service incandescent filament lamps (although some 'double-life' incandescent lamps are available with a slightly lower output than normal). Although they cost much more, the need for less frequent replacement means that discharge lamps are more suitable for mounting in locations where access is difficult.

High pressure discharge lamps have a disadvantage in use in situations where interruptions of supply may occur, because they take from one to twenty minutes to cool down and restrike, according to the type of circuit used. Consequently, if any danger from black-out due to a power failure exists in a building, it is essential that emergency lighting is provided whatever the main light source.

Use luminaires with as high as possible a light output ratio (efficiency) consistent with their function.

The highest light output efficiency does not necessarily result in the best illumination; a bare lamp luminaire is inefficient in directing light on to the working plane. A reflector round a lamp to concentrate the light below is more efficient but will probably not produce a satisfactory working environment without additional lighting. As a general guide, luminaires with prismatic control suspended below a ceiling perform their function more efficiently than those distributing their light by diffusion or those recessed into ceilings or soffits. It is important to make sure that the luminaires comply with discomfort glare requirements.

Attempts to improve illuminance on the working plane or to reduce power loading by lowering the mounting height of the luminaires, may result in patchy lighting and loss of light reflected from the ceiling. Upward light is not wasted, for it reduces the contrast of the luminaire with its background and thus reduces the discomfort glare effect; it improves the appearance of the interior by avoiding a 'dark tunnel' effect; it also provides an indirect component to the lighting to soften shadows.

Provide the necessary illuminance at the task or in the task areas by local or localised 'Task lighting' and provide the general lighting of the interior for circulation, visual appearance, background to task areas, etc, by 'Ambient lighting' at a lower illuminance.

The value of a system of 'Task/ambient lighting' or 'Task/building lighting' will depend very much on the extent and pattern of the distribution of tasks around the interior and the frequency with which these change. Such an arrangement is frequently used in the home, where table lamps or floor standards provide the light required for reading or sewing while centre-lights or wall lights provide the background.

The aim of such lighting is to direct and maintain attention to the work by giving it a higher luminance than the background, which should be less bright and capable of resting the eyes when looking up. Too dark a background to the work area will produce a harsh and uncomfortable contrast, so the general lighting must not provide too low a luminance. A designed working plane illuminance of one-third of the task illuminance should be the minimum elsewhere in the room.

Systems of task-plus-ambient lighting are not suitable for all interiors; for example, they are unsuitable where provision must be made for the same level of visual task to be performed anywhere in the interior at any time. Even where the location of tasks can be strictly defined, arrangements must be possible for luminaires to be mounted close to the task on desk bench or machine, or else to be suspended from the ceiling, wall or overhead equipment. These luminaires can generally be equipped with lamps of lower power than those in general lighting luminaires and less of them may be required where the task areas are well separated in the interior. Whatever the arrangement, the luminaire requires both an electrical supply to feed it and also space in which it can be fitted. There is responsibility also on the users to avoid maltreatment and a need for frequent maintenance.

A further advantage of task lighting is that it permits the arrangement of incident light in a way which will maximise the contrast of the task. As an example, the most common task in an office is reading printed or written material where visibility depends on the contrast between the ink or pencil mark and the surrounding paper. This contrast can be changed by changing the direction of the light. In an interior lit by an array of luminaires mounted on the ceiling, it is inevitable that the light from some luminaires will be reflected in the direct line of sight of the observer, so that shininess of ink or paper will produce lower visual contrast (reflected glare). Local lighting can be obliquely set so that task illumination is not in the plane of the observer's eye and the contrast of the task may, therefore, be appreciably improved.

Calculations indicate that a given illuminance provided by oblique local lighting should produce the same visibility of written or printed matter as general lighting at a somewhat higher illuminance.

Keep existing luminaires, lamps and room surfaces clean by increasing the frequency of cleaning.

In a new installation, this can enable the required illuminance to be maintained with fewer sources or less power. In an old installation, improved maintenance (including the replacement of fluorescent and high pressure discharge lamps at intervals not longer than their nominal life) will provide more light for the same consumption of energy. Whether it is advisable to reduce the total number of light sources in an existing installation to take advantage of a higher efficiency resulting from improved maintenance will depend on whether this can be done without any noticeable reduction in uniformity of illuminance on the working areas. Any local reduction in illuminance will obviously be less acceptable at a working point than in a circulation area.

Reducing unnecessary use

It is a matter of common observation that lights are often fully on in parts of buildings when no, or very few, people are in occupation and also when daylight is providing a high illuminance over at least some part of the working area. This over-use arises in different ways but most frequently by not switching off rather than by switching on unnecessarily. However, if too large an area of lighting is controlled by one switch the requirements for light by one individual may lead to large numbers of luminaires being switched on when only one or two are really required. Such a situation might arise from working in a place which is particularly poorly daylit or from working in a large room when no one else is present.

Manual Controls

Controls should at least permit individual rows of luminaires parallel to window walls to be controlled separately, and control systems (both mechanical and electronic) have been installed in some buildings which permit individual luminaires in a large installation to be switched by the occupants most affected. Switches should be as near as possible to the luminaires which they control, and one system which has been effective uses cord-operated ceiling switches adjacent to each luminaire. A technically feasible system, but one with which there is little experience yet, has electronic controls (ultrasonic or infra-red) placed on occupants' desks to give them control of one or more luminaires; a master control of this type would avoid any necessity for wiring to switches on walls.

Time Controls

If the occupation of a building effectively ceases at a fixed hour every working day, it may be worth installing a time control so that most of the lighting is switched off soon after this time. Arrangements may need to be made, however, for individuals working late to override part or all of the switching with subsequent automatic switching off. The building cleaning routine may also need special arrangements; sequential control of lighting may be appropriate when a cleaning gang move from floor to floor. Arrangements must be made however, to ensure that no-one ever has to enter an unlighted space or to be in a space where all the lighting is out of their control.

Photo-electric Controls

Failure to switch off lights in areas receiving sufficient daylight is another major cause of energy waste. This can occur when the lights are switched on, say at the beginning of the day when daylight alone is insufficient, and remain on when the daylight later provides more than the illuminance to which the artificial lighting was designed. Photo-electric control can ensure that the lighting cannot be turned on or remain on when the daylight provides the required illuminance by itself. In interiors where there is a large range of daylight factors, eg a fairly deep interior with two or more rows of luminaires running parallel with the window wall (or walls), it may be advantageous to use a separate controller for each row.

On-off control

An on-off switch controlled by the level of daylight produces a sudden change of illuminance on the working plane of roughly two to one if it is set to switch off the artificial lighting when daylight alone could provide the same illuminance. There is considerable evidence that the occupants of a room find it unsatisfactory if large areas of lighting are controlled in this way, although, it appears to be more acceptable if, say, the outside row of luminaires close to a wall with windows admitting a reasonable amount of daylight are controlled in this way. This is mainly because switching will be infrequent.

Top-up control

Equipment is available to control the light output of fluorescent lamps so as to top-up the daylight when it fails to reach the design level of the artificial lighting by itself. With this system, the artificial lighting is not fully on unless daylight falls to a negligible level. As daylight increases, the output of the lamps falls to keep the illuminance provided by the combination of the two

sources constant until, when daylight alone is adequate, the lamps are switched off completely. Conversely, as daylight falls below the illuminance which the artificial lighting could provide, the lamps are switched on at an almost imperceptibly low output which increases progressively to maximum as the daylight illuminance falls towards zero. Clearly such a system will use less energy than one which switches the lighting on fully for the whole time that the daylight is below the design illuminance, but more saving can be made if some positive action is needed by the occupants to initiate the switching-on action of the controller.

Energy savings

Change of light source

The improvements in efficiency may be summed up by expressing the relative efficacies (taking gear losses into account) as follows.

Lamp	Relative Efficacy
General Service	
Incandescent filament	0.83 - 1.5 (100W lamp = 1)
'Deluxe' fluorescent	1.7 - 3.75
High efficiency fluorescent	3.75 - 5.4
HP Mercury	3.75 - 5.8
HP Sodium	5.0 - 9.0

The above figures cover the range of lamps commonly used, as the efficacy varies with the wattage loading.

Luminaire light output ratio (LOR)

A recessed opal diffuser luminaire can have a light output ratio of 40 percent, while a recessed one with a prismatic diffuser can have an LOR of 48 percent. If mounted below the ceiling, the LOR can increase to 75 percent, an improvement of light emitted of 87 percent and 56 percent respectively.

Task/ambient lighting

The reduction of installed lighting power achieved by providing task illuminance in conjunction with lower ambient illuminance will depend very greatly on the density of occupation of the space. One office with a rather low density of 15 sq. metres per person achieved a reduction of 44 percent in installed lighting load by using 20 Watt fluorescent lamps in local lights at each side of the desks and in adjustable drawing board lamps. This however, may represent somewhat higher than average savings in relation to the normal density of office occupation.

In the example quoted, measurements of contrast rendering indicated that although the new installation provided only 80 percent of the horizontal illuminance on the task which the previous installation produced, there should have been a net improvement in task visibility.

Manual switching

Any reduction in energy use resulting from improved accessibility or flexibility in switching will clearly be dependant on the patterns of activity in the space. In the installation referred to in the previous paragraph, the fact that several of the office staff had a great deal of outside work and consequently their desk lights were not turned on when they were absent led to a total energy saving over a year's operation of nearly 83 percent of the energy used by the original installation. On the other hand, on one floor of a new office building where ceiling pull switches were installed to operate individual luminaires in a large open office, most luminaires tended to be left on the whole time the room was occupied. On another floor of the same building, however, with the same switching arrangement, but a different arrangement of working groups and desk locations, about one-third of the luminaires were usually off.

In a series of random visits involved in a survey of 50 offices, it was found that despite the 'switch it off' campaign in progress at the time, a potential saving of around 11 per cent of the power in use could have been made by switching off the lights which were not required at the time. Increased facility of operation or clarity of control panel identification could well have helped to convert some of this potential into an actual saving. Rearrangement of the switching to improve flexibility of control could, moreover, have doubled the potential saving.

Time control

At least one survey has shown that the energy consumed in an office building can be much greater (by up to 30 percent) than can be accounted for by the full lighting load operating for the normal working day. However, the extent to which savings can be achieved by time control of the lighting depends on the extent of late occupation, the cleaning routine and the security patrol arrangements. In a school study, it was clear that the lights were not finally turned off until some time between 22.00 and 23.00 hrs, presumably when the caretaker made his final rounds, although adult classes ended at 21.30. Although this use accounted for less than 0.5 per cent of the lighting energy consumed, 90 to 95 per cent of the lighting remained on over the lunch-hour even in the summer, accounting for some nine per cent of the total use, and some of this could also be controlled by a time switch. There is evidence, moreover, that once having been switched off, the lighting is less likely to be switched back on manually on return after lunch.

Photo-electric control

The savings achievable by substituting photo-electric control for normal manual switching depend partly on the amount of daylight entering the space and partly on what use the occupants made of the original manual switching arrangements but trial installations in offices and schools showed savings of around 30 percent of lighting energy.

Luminaire maintenance

Typically the light output of a luminaire may fall to about 75 percent of the initial light output due to soiling during the first six months use and to about 70 percent over a further six months; thus the penalty for doubling the length of the cleaning cycle might be a ten per cent additional loss of light. A similar loss may be incurred by lengthening the period of lamp replacement to 1200 hours of running from 7000 hours for a fluorescent lamp or to 9000 hours from 7000 hours for a mercury halide lamp.

Increasing the reflectances of room surfaces by redecoration can have an important effect on the illuminance on the working plane. If a room with ceiling reflectance 50 percent, wall reflectance 30 percent, and floor reflectance 10 percent is redecorated so that the reflectances are increased to 70, 50 and 30 percent respectively, the illuminance from a diffusing luminaire may be increased by 20 percent.

Costs and savings

The cost of most of the measures discussed is small in relation to the energy saved, even as additions or replacement in an old building. In a new building some of the improvements in manual control can be cheaper than installing the conventional wiring runs for wall switches. Cost effectiveness analysis has been applied to some of the measures making some reasonable assumptions about circumstances, and high on the scale of internal rate of return comes the simple automatic on-off control of lighting for areas with generous amounts of day-lighting in new office buildings; rather lower is the conversion to task/ambient lighting, followed by the replacement of incandescent tungsten lamps with fluorescent lamps.

The improved life and efficacy of fluorescent lamps compared with incandescent lamps has the effect that the cost of one lumen-hour of light from the former is about one third of that from the latter, in spite of the higher cost of the lamps. There is, however, a commitment to the extra capital cost of the control gear and of more expensive luminaires.

A further halving of the cost of light can be achieved by changing to high pressure sodium discharge lamps, but very little further reduction is possible by changing to high pressure mercury lamps (either halide or fluorescent). The advantage of these high pressure discharge lamps is that they are available in higher wattages and therefore higher total light outputs, so fewer luminaires are needed provided the mounting is sufficiently high to give the required evenness in illuminance over the working area.

Even at the present stage of development, photo electric dimming control could be cost effective in many new buildings. Relative energy costs would need to increase significantly however, or equipment costs fall considerably, before it is likely to be cost-effective to refit existing buildings. A course which would allow the possibility of easy installation at an appropriate later date would be the installation of an extra conductor wire when wiring new buildings.

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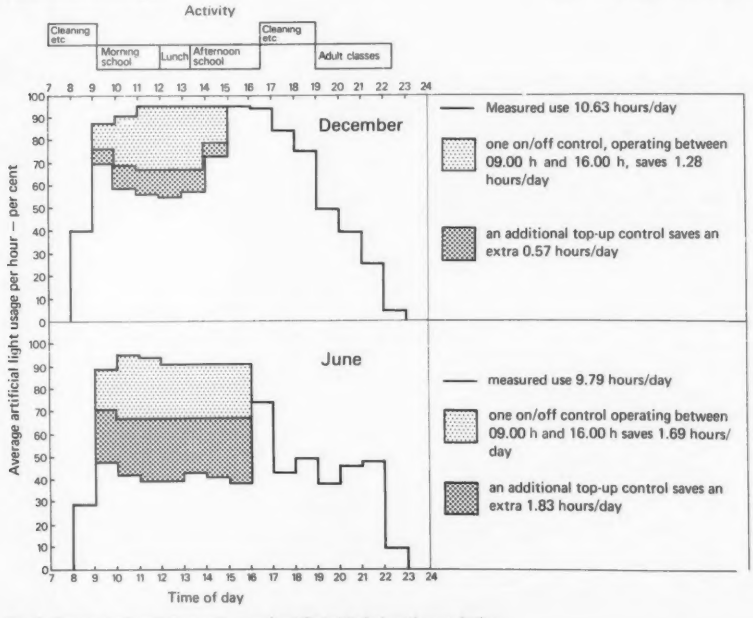
Activity
Cleaning etc
Morning school
Lunch
Afternoon school
Cleaning etc
Adult classes
December
Measured use 10.63 hours/day
one on/off control, operating between 09.00 h and 16.00 h, saves 1.28 hours/day
an additional top-up control saves an extra 0.57 hours/day
June
measured use 9.79 hours/day
one on/off control operating between 09.00 h and 16.00 h saves 1.69 hours/day
an additional top-up control saves an extra 1.83 hours/day
Average artificial light usage per hour — per cent
Time of day

Fig 1 Pattern of activity and use of artificial lighting through the day in a deep-plan secondary school. Possible savings by using automatic controls are shown by the shaded areas.

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